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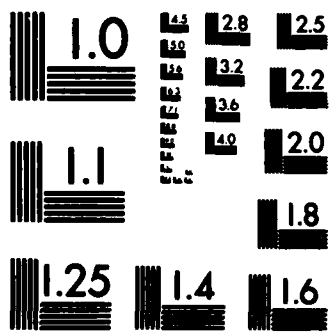

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SPACE-VARIANT OPTICAL SYSTEMS

Annual Technical Report

on

AFOSR Grant 79-0076

(Sept. 30, 1982 - Sept. 30, 1983)

by

John F. Walkup and Thomas F. Krile

Principal Investigators

November, 1983

Optical Systems Laboratory

Department of Electrical Engineering/Computer Science

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Both analytical and experimental investigations of 2-D space-variant optical processing techniques have been conducted. The investigations have included (1) the fabrication and quality testing of binary phase masks for multiplex holography; (2) a study of various techniques for using 1-D processors to perform 2-D processing and (3) a study of techniques for space-variant numerical optical processing.

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ABSTRACT

Both analytical and experimental investigations of 2-D space-variant optical processing techniques have been conducted. The investigations have included (1) the fabrication and quality testing of binary phase masks for multiplex holography; (2) a study of various techniques for using 1-D processors to perform 2-D processing and (3) a study of techniques for space-variant numerical optical processing.

RESEARCH OBJECTIVES

During the funding period from September 30, 1982 to September 30, 1983, our major research objective has continued to be the simultaneous analytical and experimental investigation of optical techniques for performing two-dimensional (2-D) space-variant (generalized linear) operations. Major topics of investigation this past year have included (1) completion of an investigation into fabricating and testing quality binary phase masks for use in reference beam encoding for multiplex holography (2) various techniques, both incoherent and coherent, for performing 2-D processing with 1-D processors, and (3) an analytical investigation of techniques for numerical optical processing. Details of these studies are provided in the following sections.

SUMMARY OF RESULTS

(1) Computer Multiplexed Holography

The goals for this project were threefold: 1) to produce binary phase diffuser masks on photoresist using our laser scanning facility, 2) to develop tests for checking the quality of the masks, and 3) to try out the masks in two optical signal processors employing multiplexed holography. These goals have now been met [1,2].

The laser scanner writing facility [3] consists of an argon-ion laser with beam-forming optics in which the beam is shuttered with an acoustic-optic modulator and is positioned with X-Y scanning galvanometer mirrors. A Compucolor II microcomputer computes and stores the required phase codes, controls the shutter and X-Y scanning mirrors, and corrects shutter times for particular recording medium characteristics. The medium used for the phase masks was AZ 1350J photoresist. A write wavelength of 4579 Å was used because, even though the photoresist is more sensitive to the laser's UV line, the 4579 Å line was more powerful and much more stable. A large number of binary phase masks were produced utilizing two-dimensional gold codes and random checkerboard patterns as the phase functions [4]. Mask dimensions ranged from 64 x 64 to 127 x 127, with 18 micron pixels.

The testing of phase mask quality was accomplished using four techniques. In the initial stages of determining required exposure and development times to obtain a 180° phase shift, scanning electron microscope photos were used to obtain step function depth profiles. An A-scope (interference microscope) was then used to determine depth profiles and true phase shifts of individual mask cells, or pixels. In order to check the cross-correlation properties of pairs of code masks, a joint transform correlator system was used. The masks to be

tested were the correlator's input, and the joint Fourier transform magnitude was recorded on film. This film was then input to an optical Fourier transformer and the output included the cross-correlation function desired. Comparisons were made between the cross-correlation of ground glass diffusers and the Gold code masks. Although the Gold code correlations exhibited some horizontal and vertical structure, the results were encouraging, particularly as compared to the results one would obtain with amplitude-only masks. A new test, which we call the power ratio test, was developed to determine the overall quality of an entire mask. It entails taking the optical Fourier transform of a mask and comparing the power in the D.C. term to the total power in the Fourier plane. This test provides a simple and yet very sensitive way to measure how close one has come to a 180^o phase shift between adjacent pixels [1].

Finally, some of the phase masks produced were utilized in two multiplexed holography optical processors. In the first case, our technique for representing space-variant systems using multiplex holography with coded reference beams was implemented [5,6,7,8]. A 2x2 point imaging system was selected as the space-variant system to be represented so that results could be compared to previous results which used ground glass as the phase encoders. In this work, four 127 x 127 Gold-code phase masks were produced and used to encode the reference beams. Upon playback, the undesired crosstalk terms were greatly reduced, but not as much as in the ground glass case. This is to be expected since the spatial bandwidth of the ground glass is much larger than for the discrete phase code, and consequently ground glass correlation properties are much better. However, the Gold code phase masks are less critical to position and are easy to duplicate.

A second method for representing a space-variant system holographically utilizes computer generated holograms (CGH's) [9-10]. In this case, the entire hologram, consisting of the functions to be recorded along with the coded reference beams, is produced and multiplexed in a computer and plotted using Burckhardt's method as a binary amplitude function [11]. Then the individual functions stored in the CGH can be retrieved in an optical system by using input phase masks corresponding to the reference beam codes used in constructing the CGH. In this experiment, 64 x 64 Gold code phase masks were used to retrieve two functions stored on multiplexed CGH. The functions were visible but not ideal because there was crosstalk between them. This is because a 64 x 64 code is really quite short and does not have very good cross-correlation properties. On the whole, however, the coded phase masks performed as expected.

In summary, we now have a tested and proven system for producing and evaluating high resolution binary phase functions on a photoresist medium.

2) White-Light 2-D Processing with Tandem 1-D Processors

As was noted in our November, 1982 Annual Report, a proof-of-principle experiment has been completed in which two tandem 1-D space-variant processors were used, along with a color-encoded input and a white light source, to perform a 2-D space-variant operation [12-14]. We assumed a separable system point spread function and further assumed that both the input and point-spread functions were real-valued and positive. Similar results have also been obtained independently, using variations of our technique, by Bartelt [15] and Indebetouw [16]. A significant advantage of the assumption of a separable point spread function is that the space bandwidth product of the input can be equal to the space-bandwidth product of the system, rather than being limited to the square-root of the latter.

Unfortunately we were not able to do significant additional work on investigating this technique during the 1982-83 funding period due to the fact that Mr. J.M. Adams, the graduate research assistant working on the project, left the graduate program at Texas Tech University soon after completing his M.S. degree work.

3) <u>Projective Mappings and Other Alternatives</u>

During the past year we have initiated a study of several techniques which will, in principle, permit us to perform 2-D space-variant processing (either coherently or incoherently) with 1-D processors. This work, as mentioned in earlier reports, was motivated by our earlier work on generalized coherent 1-D space-variant processors plus our recent results [12-14] on white-light space-variant processors. It is also motivated by the demonstrated successes reported in recent years with 1-D acousto-optical signal processors and the successes of investigators such as H.H. Barrett with projective mapping techniques such as the Radon transform [18].

One technique we are investigation is the use of the falling raster [19-20], since the 2-D spatial frequency spectra of rastered 1-D signals has been the subject of recent studies in spectral analysis. Our goal is to, where possible, decompose the 2-D space-variant operation into a succession of 1-D operations. If the space-variant system is, for example, invariant within each row of a rastered input, decomposition will be straightforward. Another possibility is to separately code each dimension so that the orthogonal directions can be processed separately and then reassembled into a 2-D output. We have begun looking at these approaches as well as various geometrical projection

techniques which might be invertible-i.e. one processes a series of 1-D projections of 2-D data and then inverts the processed projections to obtain the appropriate 2-D output. It is hoped that preliminary results will be available by the time of submitting the renewal proposal for the 1983-84 funding year.

4) Numerical Optical Space-Variant Processing

A key to understanding space-variant optical processing is that incoming data at different spatial locations undergo different mathematical operations or mappings. One area in which we are making significant progress on the grant is in developing optical processors which perform binary arithmetic operations such as multiplication, addition, and subtraction, using a high degree of parallelism. By putting off the "carry" operations as long as possible, our binary multiplication techniques should, we believe, be very fast.

Our approaches utilize Hughes liquid crystal light valves (either standard or variable grating mode devices) [21-23]. The input variable is intensity. The multiplier is sampled in sets of two binary bits. Depending on the values of these two bits, an intensity-to-spatial-frequency translation is made. The multiplicand is imaged on the liquid crystal light valve. It is also imaged after it is shifted. The values of the binary digits in the multiplier then determined the spatial location of the outputs of the light valve - effectively representing the operation of the multiplication of the multipler and multiplicand bits. The addition of the intermediate products is also performed by the use of the LCLV. Since the 2-bits-at-a-time subproducts may be done in parallel, the algorithm should be fast. Another advantage is that no *a priori* knowledge of the multiplicand is required in this system.

We have also been considering a second approach in which color is used as a parameter. This technique is similar to the one outlined above, but here the necessary color-to-space translation is performed by the use of a prism.

We are definitely encouraged by the results obtained to date on this particular project, since we believe that a major application area for space-variant optical processors will be in providing the required interconnections in the numerical optical processors [24] which are presently generating so much interest in the field of optical computing.

References:

1. S. B. Chase, "Fabrication of Binary Phase Diffusers for Space-Variant Processing," M.S. Thesis, Department of Electrical Engineering, Texas Tech University, Lubbock, TX, December, 1983.

2. S. B. Chase, T.F. Krile, and J.F. Walkup, "Binary Phase Diffusers for Space-Variant Processing," Optical Soc. of Am., 1983 Annual Meeting, New Orleans, October, 1983.

3. B. H. Jones III, "A Laser Plotter for Optical Processing," M.S. Thesis, Texa Tech University (1982).

4. R. Kasturi, "Space-Variant Processing Using Phase Codes and Fourier-Plane Sampling Techniques," M.S. Thesis, Texas Tech University (1980).

5. L. M. Deen, J. F. Walkup, and M. O. Hagler, "Representation of Space-Variant Optical Systems Using Volume Holograms," Appl. Opt., 14, 2438-2446 (1975).

6. T. F. Krile, R. J. Marks, J. F. Walkup, and M. O. Hagler, "Holographic Representations of Space-Variant Systems Using Phase Coded Reference-Beams," Appl. Opt., 16, 3131-3135 (1977).

7. T. F. Krile, M. O. Hagler, W. D. Redus, and J. F. Walkup, "Multiplex Holography with Chirp Modulated Binary Phase Coded Reference-Beam Masks," Appl. Opt., 18, 52-56 (1979).

8. M. I. Jones, "Multiplex Holography for Two-Dimensional Space-Variant Optical Processing," M.S. Thesis, Texas Tech University (1979).

9. C. A. Irby, "Computer Generated Multiplex Holography," M.S. Thesis, Texas Tech University (1980).

10. C. A. Irby, M. O. Hagler, and T. F. Krile, "Multiplexed Holograms: Digital Generation and Optical Retrieval," Appl. Opt., 21, 169-171 (1982).

11. C. B. Burckhardt, "A Simplification of Lee's Method of Generating Holograms by Computer," Appl. Opt., 9, 1949 (1970); 9, 2813 (1970).

12. J. M. Adams, J. Shamir, T. F. Krile, and J. F. Walkup, "Two-Dimensional Space-Variant Procesing Using One-Dimensional Processors," J. Opt. Soc. Am., 72, 1720 A (1982).

13. J. M. Adams, "Space-Variant Two-Dimensional Processing Using Color-Encoded One-Dimensional Processors," M.S. Thesis, Dept. of Electrincal Engineering, Texas Tech University, December, 1982.

14. J. M. Adams, J. F. Walkup, T. F. Krile, and J. Shamir, "Two-dimensional White-Light Space-Variant Processing," SPIE Procedings, vol. 388, pp. 30-37 (1983).

15. H. Bartelt, "One-Dimensional Image Transformation in White-Light," Optics Communications, 38, 239 (1981).

16. Private communications from Dr. G. Indebetouw, Virginia Polytechnic Institute and State University, 1983.

17. R. J. Marks II, J. F. Walkup, M. O. Hagler, and T. F. Krile, "Space-Variant Processing of One-Dimensional Signals," Appl. Optics, 16, 739 (1977).

18. H. H. Barrett, "Optical Processing in Radon Space," Optics Letters, 7, 248 (1982).

19. W. T. Rhodes, "The Falling Raster in Optical Signal Processing," (to be published in Transformations in Optical Signal Processing, W. T. Rhodes, J. R. Fienup, and B. E. A. Saleh, eds., SPIE, Bellingham, WA, 1984)..

20. W. W. Stoner, W. J. Miceli, and F. A. Horrigan, "One Dimensional to Two-Dimensional Transformation in Signal Correlation," Science Applications, Inc., Bedford, MA, 1982 (internal report).

21. B. H. Soffer, D. Boswell, A. M. Lockner, P. Chavel, A. A. Sawchuk, T. C. Strand and A. R. Tanguay Jr., "Optical Computing with Variable Grating Mode Liquid Crystal Devices," SPIE Proceedings, vol. 232, pp. 128-136 (1980).

22. W. P. Bleha, L. T. Lipton, E. Wiener-Avnear, J. Grinberg, P.G. Reif, David Casasent, H. B. Brown and B. V. Markevitch, "Applications of the Liquid Crystal Light Valve to Real-time Optical Data Processing," Optical Engr. 17, 371-384. (1978).

23. M. T. Fatehi, K. C. Wasmundt and S. A. Collins, Jr., "Optical Logic Gates Using Liquid Crystal Light Valve: Implementation and Application Example," Appl. Opt., 20, 2250-2256 (1981).

24. D. Psaltis, D. Casasant, D. Neft and M. Carlotto, Accurate Numerical Computation by Optical Convolution," SPIE Proceedings ,vol. 232, pp. 151-156 (1980).

RESEARCH PERSONNEL (1982-83)

1. Faculty

   Dr. J. F. Walkup, Co-Principal Investigator, Professor
   Dr. T. F. Krile, Co-Principal Investigator, Associate Professor

2. Graduate Students

   J. M. Adams — S. Chase

   N. Patkar — L. Blanchard

   D. Lojewski — S. Lin

3. Undergraduate Laboratory Assistants

   B. Boren

   A. Ling

   M. Metscher

COMPLETED THESES (1982-83)

1. J. M. Adams, "Space-Variant Two-Dimensional Processing Using Color-Encoded One-Dimensional Processors," M.S. Thesis, Department of Electrical Engineering, Texas Tech University, December, 1982.

RECORD OF JOURNAL PUBLICATIONS ON AFOSR-75-2855 and 79-0076

Journal Articles Published

1. L. M. Deen, J. F. Walkup and M. O. Hagler, "Representations of Space-Variant Optical Systems Using Volume Holograms," Appl. Optics, 14, 2438-2446 (1975).

2. R. J. Marks II, J. F. Walkup and M. O. Hagler, "A Sampling Theorem for Space-Variant Systems," J. Opt. Soc. Am., 66, 918-921 (1976).

3. R. J. Marks II, J. F. Walkup, M. O. Hagler, "Line Spread Function Notation," Appl. Optics, 15, 2289-2290 (1976).

4. R. J. Marks II, J. F. Walkup, M. O. Hagler, and T. F. Krile, "Space-Variant Processing of 1-D Signals," Appl. Optics, 16, 739-745 (1977).

5. R. J. Marks II, J. F. Walkup and T. F. Krile, "Ambiguity Function Display: An Improved Coherent Processor," Appl. Optics, 16, 746-750 (1977); addendum, 16, 1777 (1977).

6. T. F. Krile, R. J. Marks II, J. F. Walkup and M. O. Hagler, "Holographic Representations of Space-Variant Systems Using Phase-Coded Reference Beams," Appl. Optics, 16, 3131-3135 (1977).

7. R. J. Marks II, J. F. Walkup, and M. O. Hagler, "Sampling Theorems for Linear, Shift-Variant Systems," IEEE Trans. on Circuits and Systems, CAS-25, 228-233 (1978).

8. R. J. Marks II and S. V. Bell, "Astigmatic Coherent Processor Analysis," Optical Engineering, 17, 167-169 (1978).

9. T. F. Krile, M. O. Hagler, W. D. Redus, and J. F. Walkup, "Multiplex Holography with Chirp-Modulated Binary Phase-Coded Reference Beam Masks," Appl. Optics, 18, 52-56 (1979).

10. R. J. Marks II, J. F. Walkup, and M. O. Hagler, "Methods of Linear System Charactericition Through Response Cataloging," Appl. Optics, 18, 655-659 (1979).

11. R. J. Marks II, M. I. Jones, E. L. Kral, and J. F. Walkup, "One-Dimensional Linear Coherent Processing Using a Single Optical Element," Appl. Optics, 18, 2783-2786 (1979).

12. J. F. Walkup, "Novel Techniques for Optical Information Processing: An Introduction," Appl. Optics, 18, 2735-2736 (1979).

13. J. F. Walkup, "Space-Variant Coherent Optical Processing," Optical Engr., 19, 339-345 (1980).

14. M. O. Hagler, R. J. Marks II, E. L. Kral, J. F. Walkup, and T. F. Krile, "Scanning Technifque for Coherent Processors," Appl. Optics, 19, 4253-4257 (1980).

15. R. Kasturi, T. F. Krile, and J. F. Walkup, "Multiplex Holography for Space-Variant Processing: A Transfer Function Sampling Approach," Appl. Optics, 20, 881-886 (1981).

16. C. A. Irby, M. O. Hagler, and T. F. Krile, "Multiplex Holograms: Digital Generation and Optical Retrieval," Appl. Optics, 21, 169-171 (1982).

17. E. L. Kral, J. F. Walkup, and M. O.Halger, "Correlation Properties of Random Phase Diffusers for Multiplex Holography," Appl. Optics, 21, 1281-1290 (1982).

18. M. I. Jones, J. F. Walkup, and M. O. Hagler, "Multiplex Hologram Representations of Space-Variant Optical Systems Using Ground-Glass Encoded Reference Beams," Appl. Optics, 21, 1291-1297 (1982).

Journal Articles in Press

1. R. F. Carson, J. F. Walkup, T. F. Krile, "Incoherent Optical Processing: A Tristimulus-Based Method," (submitted to Appl. Optics, Dec. 1983).

Journal Articles in Preparation

1. S. B. Chase, T. F. Krile and J. F. Walkup, "Simple Tests for Binary Phase Mask Quality," (to be submitted to Optical Engineering).

Scientific Reports

1. R. J. Marks II, "Space-Variant Coherent Optical Processing, " Scientific Report AFOSR-75-2855-1, Optical Systems Laboratory, Department of Electrical Engineering, Texas Tech University, Lubbock, Texas, December 1, 1977.

2. M. I. Jones and E. L. Kral, "Multiplex Holography for Space-Variant Optical Processing," Scientific Report AFOSR-75-2855-2, Optical Systems Laboratory, Department of Electrical Engineering, Texas Tech University, Lubbock, Texas, September 1, 1979.

3. R. Kasturi, "Space-Variant Processing Using Phase Codes and Fourier-Plane Sampling Techniques," Scientific Report AFOSR-79-0076-1, Optical Systems Laboratory, Department of Electrical Engineering, Texas Tech University, Lubbock, Texas, June 1, 1980.

INTERACTION ACTIVITIES (1981-82)

A. Conference Papers Presented

1. J. M. Adams, J. Shamir, T. F. Krile, and J. F. Walkup, "Two-Dimensional Space-Variant Processing Using One-Dimensional Processors," J. Opt. Soc. Am., 72, 1720A, 1982 Annual Meeting, Optical Society of America, Tucson, AZ, October 1982.

2. J. M. Adams, J.F. Walkup, T. F. Krile, and J. Shamir, "Two-Dimensional White-Light Space-Variant Processing," SPIE Conf. on Advances in Optical Information Processing, Los Angeles, CA (SPIE Vol. 388), January 1983.

B. Other Activities

1. Participated in 1983 International Optical Computing Conference, Boston, MA, April, 1983 (J.F. Walkup, T. F. Krile).

2. Participated in ARO/AFOSR-sponsored Workshop on Optical Methos for Multi-Sensor-Array Data Processing, Callaway Gardens, GA, May 1983 (J. F. Walkup).

3. Visited laboratory of Prof. J. W. Goodman at Stanford University, July, 1983 (J. F. Walkup).

4. Invited to serve as Chairman of Technical Group on Optical Processing, IEEE Computer Society, beginning in January, 1984 (J. F. Walkup).

5. Invited to serve as Newsletter Editor, Technical Group on Optical Processing, IEEE Computer Society, beginning in January, 1984 (T. F. Krile).

6. Invited to serve as member of Ad Hoc Committee on Science Education, Optical Society of America (J. F. Walkup).

7. Invited to serve as a member of the SPIE Education Committee (T. F. Krile).

SUMMARY OF SIGNIFICANT ACCOMPLISHMENTS

1. Produced binary phase diffuser masks on photoresist using our laser scanner facility. The masks were tried out in two optical signal processors using multiplex holography and performed well.

2. Developed tests for checking the quality of the binary phase masks.

3. Completed proof-of-principle experiments using a white-light source, color-encoded input, and tandem 1-D space-variant processors to perform 2-D space-variant processing.

4. Expanded analytical work on the use of projective mappings and other decomposition techniques for performing either coherent or incoherent 2-D space-variant processing operations with 1-D optical processors.

5. Initiated an anayltical/experimental project on the use of novel space-variant techniques in performing binary numerical optical processing operations.

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